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Efficiency and equity in externalities: a partial equilibrium analysis

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Abstract. Externalities comprise efficiency aspects and equity aspects. The potential Pareto improvement criterion usually applied in analysis of the economics of externalities is solely concerned with efficiency aspects because it bypasses the question of interpersonal utility comparison. However, in the practice of policymaking, equity issues are often at least as important. This paper contains a partial equilibrium analysis of the question of to what extent optimization and compensation of an external cost are compatible under different schemes of regulation and internalization, and in different model settings: the standard textbook model, a model in which defensive activities on behalf of the victim are allowed for, and a model in which dynamic aspects of entry – exit behaviour are investigated.

1 Introduction

The concept of external effects has been in the interest of economists ever since the days of Marshall and Pigou. Along with the development of the field of environmental economies, the theory of externalities remained a paradigm of great and even growing importance in economic science. The potential Pareto improvement criterion usually applied in analysis of the economics of externalities is solely concerned with efficiency aspects. It deliberately bypasses matters of equity, because (yet unresolved) problems associated with interpersonal utility comparison can thus be avoided. However, in the practice of policymaking, equity issues are often at least as important as matters of efficiency. This paper contains a partial equilibrium analysis of the compatibility of optimization and compensation of an external cost. Therefore, without letting go of the relatively strong efficiency concept of potential Pareto improvements, we will see whether satisfaction of a rather intuitive equity concept (compensation) is possible. I consider different forms of regulation and internalization, and different model settings. The paper is organized as follows. In section 2 I give some definitions of the concepts involved. Next, section 3 contains a graphical presentation of a basic model. In section 4, a more general external cost function is used, in which allowance is made for abatement and defensive activities. In section 5, some dynamic aspects are discussed, concerning entry – exit behaviour of the receptor(s) and the supplier(s) of the externality. Section 6 contains the conclusions.

2 The concepts involved with external effects

Although the concept of external effects, as well as the concepts of optimization, compensation, and internalization of externalities are widely used in economics, consensus on the exact definitions often seems to be lacking. In order to assure unambiguous interpretation of what follows, this section contains the definitions of these concepts as applied in this paper.

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First, we say that an external effect exists when an actor's (the receptor's) utility (or production) function contains a real variable whose actual value depends on the behaviour of another actor (the supplier), who does not take this effect of his or her behaviour into account in his or her decisionmaking process. This definition is in line with Mishan (1971, page 2), for instance. In the terminology proposed by Bator (1958), such externalities concern his concept of 'ownership externalities', as opposed to the 'technical externalities' (increasing returns to scale or indivisibilities in production) and 'public good' externalities he distinguishes. In the terminology of Viner (1931) and Scitovsky (1954), the above definition concerns 'technological' externalities, as opposed to 'pecuniary externalities'. These latter, which are ruled out by focusing on real variables (that is, excluding monetary variables), do not lead to shifts of production and utility functions, but merely to movements along these functions. Consequently, in the terminology of Buchanan and Stubblebine (1962), externalities as defined above are potentially 'Pareto relevant', whereas pecuniary externalities are not (see also Mishan, 1971, page 2). The final condition in the definition distinguishes externalities from other types of unpriced interactions, for example, barter trade, violence, jealousy, altruism, or goodwill-promoting activities. Such phenomena differ fundamentally from external effects, both in a theoretical and in a policy-relevance respect. According to Mishan (1971, page 2), "the essential feature of an external effect [is] that the effect produced is not a deliberate creation but an unintended or incidental by-product of some otherwise legitimate activity". The unresolved tension between the receptor, facing a quantitative constraint on the 'consumption' of the externality, and the supplier, who has no a priori interest in the magnitude of the externality, can only persist provided there is no market on which the externality is traded. Such market failures stem from a lack of (well-defined) property rights concerning the externality, which may in turn be related to prohibitively high transaction costs.

Externalities comprise efficiency aspects and equity aspects. The first refer to the fact that, in the presence of externalities, the competitive market outcome is not Pareto efficient. The second relate to the fact that the receptors of a negative (positive) externality are clearly worse (better) off at any nonzero level of the effect, unless compensations take place. This distinction between efficiency and equity aspects leads to a distinction between the optimization and the compensation of externalities.

The *optimization* of an external effect can be defined as follows: an externality is optimized when its level is consistent with optimal resource allocation according to the compensation criterion. Therefore, the commonly used concept of the 'Pareto optimal level' of an externality implies acceptation of the potential Pareto improvement criterion for the evaluation of social welfare. According to the strict Pareto criterion, an external cost-generating activity is not allowed to be set up unless its victims are (at least) compensated. By the same criterion, however, such an activity—once in existence—can not be restricted unless the generator is compensated. On the other hand, the compensation criterion is concerned solely with allocative efficiency and allows such activities to take place as long as the victims can *hypothetically* be compensated, regardless of whether such compensations actually do take place.

The actual *compensation* of an external effect can be defined as follows: an externality is compensated when a (financial) transaction takes place between the supplier and the receptor of the effect, which compensates for the receptor's welfare effects due to the externality. Apart from such 'full' compensation, overcompensation (undercompensation) occurs when more (less) than the full value of the effect is compensated.

The *internalization* of an external effect involves the removal of its external character, making it "internal to the economic process' (see Mishan, 1971, page 3): an externality is internalized if a market for the effect comes into being.(1) Internalization typically involves either a gathering of interest (for example, a merger in case of a producer-producer externality; the standard case being when water pollution by an upstream firm damages the product of a downstream firm), or the (artificial) creation of a market on which the externality can be traded. This requires the assignment of property rights, after which Coasian negotiations between the supplier and the receptor of the effect will take place.

Finally, I will use the term *regulation* for direct government intervention by means of either price instruments or command-control measures.

In summary, along with the efficiency and the equity aspects of an externality, its optimization and its compensation can be distinguished. The distinction in efficiency and equity aspects of externalities is closely related to the fact that Pareto efficiency is defined so as to get rid of the difficulties associated with interpersonal utility comparisons (that is, equity aspects). In the following sections, I will investigate whether the satisfaction of a rather intuitive equity criterion, namely 'compensation', is possible without violation of the efficiency criterion.

3 A basic model

Figure 1 provides the standard textbook presentation of a negative external effect. A certain actor—'the producer'—performs a productivity activity Q, from which he or she enjoys net private benefits (private benefits minus private costs). However, the actor causes an external cost—say, pollution—to another actor: 'the victim'. The curves show the *marginal net private benefits* (MNPB) and *marginal external cost* (MEC) of production. Without government intervention, a production level of Q_0 prevails, where net private benefits are maximized. The social optimum is Q^*, where the net social benefits (net private benefits minus external cost) are maximized, and the dead-weight welfare loss (triangle E) is avoided. In this social optimum, a certain part of the external cost remains existent (area C). Clearly, the optimization of an external effect does not mean its minimization or maximization.

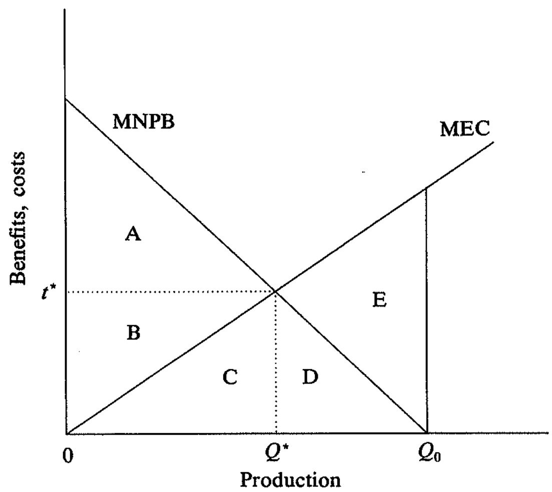

Figure 1. A basic model of external costs.

(1) Pigouvian taxation is often referred to as the 'internalization' of an external effect. However, such market-conform regulation does not actually satisfy the definition of internalization.

In the literature, certain 'standard' schemes can be found which yield this social optimum. In this paper, I consider three categories of such schemes. First, I distinguish two forms of regulation: quantitative restrictions[(2)] and Pigouvian taxation. Second, I consider direct compensation from the producer to the victim. Last, I consider two forms of internalization: a gathering of interest (that is, a merger of the victim and the producer, which will often be impossible for very practical reasons); and the assignment of property rights concerning the externality (either to the producer or to the victim) resulting in Coasian negotiations. Table 1 shows the distributional impacts of these schemes. Although in this simple setting each of them yields the efficient outcome (the maximum social welfare of A+B), they all have different distributional implications.

Table 1. The individual welfare positions associated with different schemes for optimizing externalities in a basic model.

	Producer	Victim	Regulator	Social
Nonintervention	A+B+C+D	−C−D−E	0	A+B−E
Regulation:				
Quantitative restriction (Q^*)	A+B+C	−C	0	A+B
Pigouvian tax (t^*)	A	−C	B+C	A+B
Direct compensation	A+B+C−(C) = A+B	−C+(C) = 0	0	A+B
Internalization:				
Gathering of interest	⟵ A+B	⟶	0	A+B
Coasian negotiations[a]	A+B+C+(D+E)	−C−(D+E)	0	A+B
Coasian negotiations[b]	A+B+C+(D)	−C−(D)	0	A+B
Coasian negotiations[c]	A+B+C−(C) = A+B	−C+(C) = 0	0	A+B
Coasian negotiations[d]	A+B+C −(A+B+C) = 0	−C+(A+B+C) = A+B	0	A+B

Notes: Terms between brackets indicate financial transfers between the producer and the victim.
[a] Property right lies with the producer; the producer has the extreme strongest bargaining power.
[b] Property right lies with the producer; the victim has the extreme strongest bargaining power.
[c] Property right lies with the victim; the producer has the extreme strongest bargaining power.
[d] Property right lies with the victim; the victim has the extreme strongest bargaining power.

Most of the values in table 1 can be verified with reference to figure 1. However, Coasian negotiations deserve some closer attention. The distributional implications depend on the distribution of the property rights as well as on the individual bargaining skills. The allocation of property rights determines the direction of the financial transfer; bargaining skills determine its magnitude. For both distributions of property rights, transfers between the polar values mentioned in table 1 may of course occur. These values follow from the fact that the MNPB gives the producer's minimum willingness to accept (maximum willingness to pay) for decreases (increases) in production, whereas the MEC represents the victim's minimum willingness to accept (maximum willingness to pay) for increases (decreases) in the production level. Note that, when the property right is assigned to the producer, the associated financial transfer has the direction opposite to that for compensation of

[(2)] Tradable permits are not considered, simply because we are dealing with one single producer. Such permits result in an efficient distribution of a sectoral restriction among the individual producers.

the external cost.[3] Full compensation takes place when the property rights are assigned to the victim, whereas the producer has the strongest bargaining power. As a matter of fact, direct compensation can be seen as a restricted case of Coasian negotiations. The property right is implicitly given to the victim, but the victim is not allowed to bargain over the compensation.

Table 1 indicates that the interest groups have different rankings concerning the different schemes. The producer prefers Coasian negotiations with the property rights assigned to himself or herself. He or she then may realize a welfare level above the level he or she enjoys with unrestricted production. The second favourite is nonintervention. Next comes a quantitative restriction, followed by direct compensation, and finally either Coasian negotiations with the property right assigned to the victim, or Pigouvian taxation—depending on the distribution of bargaining skills (note that the ranking of these last three depends on the assumption of rising marginal external cost). The victim prefers receiving the property rights and the associated Coasian negotiations. Next comes direct compensation, followed by any form of regulation. Then comes Coasian negotiations with the property rights assigned to the producer, and finally nonintervention. The 'gathering of interest' possibility cannot, for obvious reasons, be qualified along this criterion. These rankings may to some extent explain why some policies are used more often than others. For example, considering regulation measures, the producer prefers a quantitative restriction to Pigouvian taxation, whereas the victim is indifferent (assuming he or she does not consider the potential uses of the tax revenues). A vote-maximizing government may, therefore, prefer to use command-control measures rather than economic instruments, which seems to be confirmed by practical evidence (see also Pearce and Turner, 1990, pages 96-98).

A somewhat embarrassing shortcoming of the foregoing graphical analysis is that the MEC and MNPB curves are assumed to be stable throughout (that is, they do not shift in response to different distributions of wealth as considered in table 1). As far as the producer is concerned, this assumption is not problematic as long as we assume that he or she is a profit maximizer. However, when the victim is a utility maximizer, such an approach is legitimate only when his or her marginal utility of income is constant. This is, for instance, the case when the victim's utility function is quasilinear; that is, linear in at least one of the consumer's goods purchased in a positive amount over the relevant range and (possibly) nonlinear in the other consumer good(s), including the external cost suffered. For such utility functions, Hicksian welfare measures (equivalent variation, compensating variation) coincide with the Marshallian consumer surplus, and the victim's valuation of the external cost (that is, the position of the EC curve) is independent of income and therefore independent of any compensations paid or received (see Varian, 1992, chapter 10).

The conclusions of the basic model presented in this section are fairly straightforward. Both direct compensation and internalization of the external cost, as well as (optimal) regulation, lead to its optimization. On the other hand, neither regulation nor internalization in general leads to the compensation of the effect. After optimization by means of regulation, the victim of the effect is still confronted with the optimal level of the externality. Coasian negotiations with the property rights assigned to the victim lead to an outcome where the externality is optimized and the victim is at least fully compensated. When the producer receives the property right,

(3) The maximum transfer from the victim to the producer (D + E) mentioned assumes that the producer is truthful. If the producer pretends to consider a production level above Q_0, the victim is willing to pay more than (D + E) in order to secure Q^*. The victim does not have a comparable possibility of 'cheating'.

the associated transfers have the opposite direction. However, in this basic setting, the optimization and compensation of an external cost are not necessarily incompatible.

4 Modelling abatement and defensive measures

In the foregoing section, the actual level of external costs depends on the level of the activity (Q), only. In order to reduce the external cost, the producer of the effect can only reduce his or her activity. On the other hand, the victim can only passively suffer from the damage done to him or her. Often, however, a producer may also reduce the external cost by performing *abatement* activities, and a victim may protect himself or herself against the negative effect by means of *defensive* measures. Such possibilities for applying defensive and abatement technologies are often present in case of environmental externalities. So, polluting factories may be equipped with cleaner technologies. Likewise, victims of noise annoyance may decide to protect themselves by means of double glazing. Defensive activities in particular are relevant for the issues considered in this paper, as the compensation of external costs is often said to remove a victim's optimal incentives to protect himself or herself against the externality, thus inducing inefficiencies (see Baumol and Oates, 1988, page 24; Oates, 1983) and ruling out the compatibility of optimization and compensation. In this section, I will investigate this issue. I use the following general external cost function:

$$C = \mathrm{C}(Q, D, A)\,, \tag{1}$$

where C is the external cost; Q is the level of the externality-causing activity; D is the level of the victim's financial outlays on defensive measures; and A is the level of the producer's financial outlays on abatement activities. I assume that the following functional characteristics, representing the most plausible case, apply (subscripts denote partial derivatives):

$$C_Q > 0 \text{ and } C_{QQ} \geqslant 0\,, \tag{2a}$$

$$C_D < 0 \text{ and } C_{DD} > 0\,, \tag{2b}$$

$$C_A < 0 \text{ and } C_{AA} > 0\,, \tag{2c}$$

which indicate positive nondecreasing marginal external cost of the activity and positive diminishing marginal effectiveness of both kinds of measures. In addition, it may be postulated that:

$$C_{DQ} = C_{QD} < 0\,, \tag{2d}$$

$$C_{AQ} = C_{QA} < 0\,, \tag{2e}$$

$$C_{AD} = C_{DA} > 0\,. \tag{2f}$$

The two relationships (2d) and (2e) indicate that at higher levels of the activity, outlays on defensive and abatement actions will have more impact in terms of reducing the external cost; and, at higher levels of defensive or abatement outlays, a rise in the activity level causes smaller increases in the external cost. The third relationship (2f) states that at higher levels of defensive activities, the effect of increasing abatement will be smaller, and vice versa. Next, the producer's welfare function is given by his or her profit:

$$W^{\mathrm{P}} = \mathrm{B}(Q)-\mathrm{P}(Q)-A-T = \mathrm{N}(Q)-A-T\,, \tag{3}$$

where $\mathrm{B}(Q)$ is the private benefit and $\mathrm{P}(Q)$ is the private (production) cost of the activity; $\mathrm{N}(Q)$ is the net private benefit. A positive T indicates a financial transfer from the producer to the victim (compensation). Assume diminishing marginal net private benefits $N = \mathrm{N}(Q)$:

$$N_{QQ} < 0\,. \tag{4}$$

The victim's money metric utility function is assumed to be functionally separable in C and D, on the one hand, and the consumed bundle of all other goods (represented by a vector $\boldsymbol{x}$), on the other. This means that the preferences over the other goods are assumed to be independent of the preferences over C and D, and that the vector demand $\boldsymbol{x}$ is only a function of the price vector $\boldsymbol{p}$ of these goods. The outlays on defensive measures D, as well as compensations T, influence the consumed bundle $\boldsymbol{x}$ only via the budget constraint. Taking the victim's income M and the price vector $\boldsymbol{p}$ as given, the victim's indirect money metric utility function (which I will call his or her welfare function) can then be written as:

$$W^{\mathrm{v}} = \mathrm{e}\big(\boldsymbol{p}, \mathrm{u}(\boldsymbol{p}, M+T-D)\big) - \mathrm{C}(Q, A, D)\,. \tag{5}$$

Here, $\mathrm{u}(\boldsymbol{p}, M+T-D)$ is the indirect utility function for the other goods, giving the maximum utility available at given prices $\boldsymbol{p}$ and budget $M+T-D$ [that is, $\mathrm{u}(\boldsymbol{p}, M+T-D) = \max_x \mathrm{U}(\boldsymbol{x})$, subject to $\boldsymbol{px} = M+T-D$, where $\mathrm{U}(\boldsymbol{x})$ is the direct utility function]. The expenditure function e gives the minimum budget necessary for achieving a fixed level of utility and is therefore identical to the indirect money metric utility function. For given prices, the expenditure function is just the inverse of the indirect utility function. Furthermore, for given prices, the expenditure function is by definition equal to the budget (the minimum expenditure necessary to reach the maximum utility available at fixed prices and with a fixed budget is just equal to that budget). Therefore, the victim's welfare function (5) may be rewritten as:

$$W^{\mathrm{v}} = M+T-D-\mathrm{C}(Q, A, D)\,. \tag{6}$$

The simple postulation of C as the external cost suffered by the victim hides one particular problem inherent to external effects, namely that they are unpriced by nature. Still, C is defined as the monetary valuation of some physical external effect, $F = \mathrm{F}(Q, A, D)$, suffered, which is one of the arguments of the victim's direct utility function. For the fundamental relation between F and C, assume that defensive activities are not possible so that the D terms drop out of equation (6). It then follows from equation (6) that the victim is indifferent to simultaneous changes in T and C, and therefore in M and C, as long as $\mathrm{d}M - \mathrm{d}C = 0$. In terms of the direct utility $U = \mathrm{U}(\boldsymbol{x})$, this indifference translates into $U_M \mathrm{d}M + U_F\, \mathrm{d}F = 0$. Substituting the first equation into the second and rearranging, we find:

$$\frac{\mathrm{d}C}{\mathrm{d}F} = \frac{-U_F}{U_M}\,. \tag{7}$$

The relationship between the physical effect and its monetary value (the external cost) not only depends on how seriously the effect harms the victims' utility ($-U_F$), but is in addition inversely related to their marginal utility of income (or the value of money) U_M. This reflects the fact that the economic value of a negative external effect is defined as the victim's willingness to pay for decreases, or willingness to accept for increases in the physical effect.(4) These values are lower, the higher the marginal utility for money (ceteris paribus, the lower the victim's income). Intuitive objections against the implication that equal exposures to a physical effect imply, ceteris paribus, larger external costs for higher income groups than for lower

(4) In theory, these two measures should be equal at the margin. Empirical research with contingent valuation methods, however, suggests otherwise (see Mitchell and Carson, 1989, pages 30-38).

income groups reflect either dissatisfaction with the existing income distribution, or the assignment of some demerit character of the effect for lower income groups. Of course, the effect may also be considered a demerit good for all income groups. Therefore, straightforward application of the concept of external costs, even when explicitly taking account of equity aspects between its supplier and its receptor(s), may ignore important equity aspects *within* the population of victims.

Returning to the model, we can define the social (money metric) welfare function W as the sum of the individual welfare functions:

$$W = W^{\mathrm{p}} + W^{\mathrm{v}} = \mathrm{N}(Q) - \mathrm{C}(Q, A, D) - A - D + M. \tag{8}$$

Social welfare maximization (efficiency) is realized according to the following first-order conditions.[5]

$$W_Q = 0 \Rightarrow C_Q = N_Q, \tag{9a}$$

$$W_A = 0 \Rightarrow C_A = -1, \tag{9b}$$

$$W_D = 0 \Rightarrow C_D = -1. \tag{9c}$$

An intuitive interpretation of these results is that in the optimum, a reduction in the external cost is equally expensive for the three different ways of achieving it (that is a reduction in the level of the activity, or increases in abatement or defensive outlays). For each way, the marginal value of reducing the external cost is equal to the marginal cost of accomplishing such reductions. We assume that this optimum involves nonzero optimal values Q^*, A^*, and D^* (that is, we assume that an interior solution exists), resulting in maximum social welfare (W^*):

$$W^* = N(Q^*) - C(Q^*, A^*, D^*) - A^* - D^* + M \tag{10}$$

I will now examine whether individual welfare maximization of the victim [maximization of equation (6)] and the producer [maximization of equation (3)] is consistent with social welfare maximization [satisfaction of equations (9)].

4.1 The victim's behaviour

For the victim, as long as T is equal to zero, maximization of equation (6) is consistent with equation (9c). This indicates that the victim's behaviour is in general consistent with overall optimality: as long as the producer realizes Q^* and A^*, the victim has the optimal incentive to spend D^* on defensive activities. That is, equation (9c) gives the optimal condition for the victim's distribution of resources among the first and the second term on the right hand side of equation (5). The outcome, that the victim performs defensive activities up to the optimal level where $C_D = -1$, is not very surprising once one recalls that the (marginal) external cost is defined as the victim's willingness to pay for reductions in the physical effect. Clearly, the possibility of defensive activities simply provides the victim with a means to express this willingness to pay in the market place.[6]

(5) The resulting extremum is a welfare maximum only if the associated Hessian satisfies the necessary criteria (that is, the principal minors duly alternate in sign, the first one being negative).

(6) This point may be illustrated as follows. The victim in fact has the following indirect utility function: $\max_{x,d} \mathrm{U}(x, d)$, subject to $px + qd = M$, where d gives the physical amount of defensive measures taken and q the unit price: $qd = D$. As the marginal utility of d depends on the reduction in the physical effect F ($U_d = U_F F_d$), the first-order conditions for utility maximization include $U_F F_d - U_M q = 0$. Therefore, $F_d = q(U_M/U_F)$. Divided by q, this yields $F_D = U_M/U_F$. Using $C_F = -U_F/U_M$ from equation (7) [when allowing for defensive activities $\mathrm{d}C/\mathrm{d}F$ in equation (7) should be replaced by the partial derivative C_F], we find $C_D = -(U_F/U_M)(U_M/U_F) = -1$.

There are, however, three qualifications. In the first place, under free market conditions, the producer will generally set $Q > Q^*$ and $A < A^*$. In that case, equations (2d) and (2f) together with equation (9c) imply $D > D^*$: the victim conducts defensive actions up to a level optimal from his or her own point of view but exceeding the overall optimal level D^*.

Second, compensations may remove the victim's incentive to perform the optimal defensive activities. Two forms of compensation spring to mind: compensation of C alone, which we may label the *net external cost*, and compensation of the sum of C and D, which we will call the *gross internal cost*. Direct compensation of the net external cost ($T = C$) reduces equation (6) to:

$$W^{\mathrm{v}} = M - D\,, \tag{11}$$

which is maximized for $D = 0$. Alternatively, direct compensation of the gross external cost ($T = C + D$) reduces equation [6] to:

$$W^{\mathrm{v}} = M\,, \tag{12}$$

which means that the victim is indifferent to the actual values of C and D: the victim's welfare will be the same under all circumstances. The producer will in this case prefer the victim to undertake the optimal level of defensive outlays (D^*), as will be shown below. Clearly, under direct compensation there is no straightforward incentive for the victim to protect himself or herself against the negative external effect. This is why Baumol and Oates (1988) claim that externalities should have an asymmetric price: "a non-zero price to the 'supplier' of the externality and a zero price for the consumption of the externality" (see page 29). However, any *lump-sum compensation*, whatever value it takes (net or gross external cost, or any other value), leaves the victim's incentive to conduct defensive measures intact. In that case, equation (6) can be written as:

$$W^{\mathrm{v}} = M + \underline{T} - D - \mathrm{C}(Q, A, D) \tag{13}$$

Since $\underline{T}$ is constant, maximization is again realized according to equation (9c).

Third, when the external cost is considered to have a demerit character, the social value of its 'consumption' is considered to be higher than the victim's valuation [see equation (7)], and the level of defensive activities resulting from individual maximizing behaviour is consequently below the socially optimal level. Subsidization of defensive activities is then inevitable for social welfare maximization.

4.2 The producer's behaviour

For the producer, maximization of equation (3) is generally not consistent with equations (9a) and (9b):

$$\max_Q(W^{\mathrm{p}}) \Rightarrow N_Q = 0\,, \tag{14a}$$

$$\max_A(W^{\mathrm{p}}) \Rightarrow A = 0\,. \tag{14b}$$

Production will be above and abatement below the overall optimal levels as given by equations (9a) and (9b). For optimal regulation, a quantitative measure regarding the level of the activity (Q^*) should now be accompanied by a quantitative duty (a standard) regarding the level of abatement activities (A^*). Otherwise, the producer chooses $A = 0$, and the social optimum will not be realized. Likewise, Pigouvan taxation should provide the right incentive for the producer to choose both the optimal production level and the optimal level of abatement. This involves a tax on the activity and a subsidy on abatement (or a tax on the gap between the optimal and the actual level of abatement).[7] Of course, a combination of economic and noneconomic incentives will also do the job.[8]

Direct compensation of the net external cost ($T = C$) will, according to equation (11), result in $D = 0$. The producer will then seek to maximize the following:

$$W^{\mathrm{p}} = \mathrm{N}(Q) - \mathrm{C}(Q, A, D = 0) - A\,, \tag{15}$$

leading to suboptimal levels of Q and A, given by:

$$N_Q = C_Q \tag{16a}$$

$$C_A = -1 \tag{16b}$$

Unless the victim is somehow forced to perform defensive activities up to D^*, production will be below, and abatement above, the optimal levels because equations (2d) and (2f), implying deviations opposite to those in the nonintervention outcome. However, it is actually beneficial for the producer to propose direct compensation of the gross external cost ($T = C + D$), simply because his or her maximization problem in fact coincides with maximization of equation (8) according to equations (9a) to (9c). Hence, the producer will try and persuade the victim to undertake defensive measures up to D^*. This may be by means of (mutually beneficial) financial bids. Because D^* is the level of defensive activities where the potential benefits of bargaining are exhausted (see below), we may expect the optimal outcome. Again, direct compensations can be seen as a restricted form of Coasian negotiations. The property right is implicitly assigned to the victim, who is, however, not allowed to bargain so as to receive any transfer exceeding the gross external cost.

Lump-sum compensations, though preserving the right incentive for the victim, do not optimize the producer's behaviour, because then the producer will maximize:

$$W^{\mathrm{p}} = \mathrm{N}(Q) - A - \underline{T}\,, \tag{17}$$

which yields nonoptimal values of A and Q according to equations (14a) and (14b). Clearly, additional regulation of the producer is called for.

4.3 Internalization

Finally, I consider the internalization of the external cost. A *gathering of interest* simply leads to the social optimum, because the common objective will be to maximize equation (8). *Coasian negotiations* are a bit more complex to deal with. However, assuming that the parties will bargain over Q, A, and D, the efficient outcome will be the sole equilibrium where no incentive for bargaining is left. This can be seen with reference to equations (9a) to (9c).

[7] In order to derive the optimal subsidy on abatement activities, we can no longer express abatement simply as money expenditures, but we would have to introduce some measure of 'units of abatement'. As such an exercise does not really yield any important insights, I leave this issue aside.

[8] It may be argued that the use of standards or taxation on the emitted physical effect $E = \mathrm{E}(Q, A)$, rather than concerning both the production level and abatement activities, would offer a much simpler device. The external cost will be a nondecreasing function of E, so that a distinction can be made into $\mathrm{E}(Q, A)$ and $\mathrm{C}(E, D)$ [and $\mathrm{F}(E, D)$]. However, the determination of optimal pollution standards or taxes is not possible without knowledge of relation (1). An optimal standard E^*, consistent with $\mathrm{C}(Q^*, A^*, D^*)$ will dictate a least-cost solution to the producer of Q^* and A^*. Likewise, the equivalent tax on pollution will amount to $\mathrm{C}_M(C^*)$, dictating the same values Q^* and A^*.

Consider the case where the victim receives the property right. First, for any $Q < Q^*$: $C_Q < N_Q \Rightarrow -W_Q^v < W_Q^p$. Consequently, there exists a marginal transfer (T_Q) from the producer to the victim for which $-W_Q^v < T_Q < W_Q^p$. Therefore, both parties can gain when Q is increased up to Q^*. For the same reason, $Q > Q^*$ will not occur. In that case, $C_Q > N_Q$, and as the victim will at least require a marginal transfer equal to $C_Q(>N_Q)$, it is not optimal for the producer to choose any $Q > Q^*$. Similarly, for any $A < A^*$: $C_A < -1 \Rightarrow W_A^v > 1$. Because $W_A^p = -1$, a marginal reduction in the transfer $(-T_A)$ exists for which $W_A^v > -T_A > -W_A^p = 1$. Both parties can gain when A is increased up to A^*. But $A > A^*$ will not occur, because in that case $W_A^v < 1$. The producer is better off compensating the victim than performing extra abatement activities. Finally, for every $D < D^*$: $C_D < -1 \Rightarrow W_D^v > 0$. The victim will undertake the optimal defensive actions anyway, because the victim's welfare will be maximized at the overall optimal D^*, where $C_D = -1$ and $W_D^v = 0$. Moreover, the victim might even try to bargain over this with the producer. If his or her bargaining position is strong enough, the victim may be able to make the producer compensate for the external cost resulting from below-optimal defensive activities. The producer can gain reductions in the compensation equal to $-C_D$ from increases in D, and there exists for every $D < D^*$ a marginal transfer (T_D) for which $D_D = 1 < T_D < -C_D$. Both parties can gain from increasing D up to D^*.[9] Again, $D > D^*$ will not occur; neither when the victim is to undertake the measures, nor when the producer is compensating for excessive external cost due to below-optimal defensive actions. Along the same lines, it can be proved that also when the producer holds the property right, Q^*, A^*, and D^* result.

4.4 Conclusion to section 4

It has been stressed in the literature that compensations may remove the victim's incentive for performing the optimal level of defensive activities and are therefore not compatible with overall efficiency. Although this fear may certainly be justified when only the net external cost is compensated, direct compensations of the gross external cost leave the victim indifferent to the actual level of defensive activities. On the other hand, the producer's benefits from simultaneous increases in defensive activities and associated decreases in compensations are not exhausted before the overall optimum is reached, simply because the producer faces the full social welfare maximization problem under direct compensation of the gross external cost. We may therefore expect some form of Coasian negotiations on defensive activities to take place, leading to efficiency. Likewise, Coasian negotiations with the property right assigned to the victim will not only lead to the optimal outcome, but also at least to full compensation of the gross external cost. Furthermore, lump-sum compensations by definition leave the victim's optimal incentive intact, but require additional regulation of the producer. Therefore, (Pigouvian) tax revenues resulting from producer's regulation may be transferred in a lump-sum fashion to the victims without endangering the optimal outcome. However, pure lump-sum compensations are a theoretical construct with little practical relevance. We may conclude that compensation and optimization are not necessarily at odds with each other when defensive activities are possible; especially not as long as the victim is engaged in some form of negotiations on the compensation. Finally, if the externality is considered to be a demerit good, subsidization of defensive activities is inevitable for social-welfare maximization.

[9] It is now easy to verify that with direct compensations, the producer will try and persuade the victim to undertake D^*. If this is done by means of Coasian negotiations, D^* will indeed result.

5 Some dynamic aspects

The conclusion reached in section 4—that a victim, certainly in the absence of direct compensations, receives the optimal incentives for engaging in the optimal level of defensive activities—rests on the critical assumption that the victim takes the values of Q and A as given. In fact, for every value of D other than D^*, there are suboptimal values $Q^x \neq Q^*$ and $A^x \neq A^*$ maximizing social welfare, given the deviation $D^x \neq D^*$. Should the victim believe that, under a scheme of direct regulation of Q and A (physical measures or Pigouvian taxation/subsidization), these policies are adjusted in optimal response to the actual value of D chosen, his or her welfare function of equation (6) can be written as:

$$W^{v} = M + T - D - \mathrm{C}(\mathrm{Q}(D), \mathrm{A}(D), D). \qquad (18)$$

Maximization with respect to D now leads to:

$$C_Q Q_D + C_A A_D + C_D = -1 \qquad (19)$$

Comparison with equation (9c) shows that behaviour described by equation (19) is inconsistent with overall optimality if $Q_D \neq 0$ and $A_D \neq 0$. That is, if the regulation of the producer is indeed adjusted in optimal response to deviations of D from D^*, so that $Q_D > 0$ and $A_D < 0$, we find $C_D < -1$ and the first-order conditions for welfare optimization in equations (9a) to (9c) are violated. The victim performs defensive measures up to a certain level $D^x < D^*$. In (optimal) response to this, the regulator will make the producer set $Q^x < Q^*$ and $A^x > A^*$. A welfare optimizing regulator with complete information can avoid this problem simply by not changing the incentives given to the producer in response to the victim's behaviour. The Q_D and A_D in equation (19) are then equal to zero, and the victim is led to behave in line with overall optimality. However, the regulator may actually often wish to adjust the producer's regulation in response to the victim's activities. Particularly in dynamic contexts, where the victim(s) simply cannot be expected to react instantaneously to incentives given, the regulator may wish to do so in order to reach *sequential social-welfare maximization* (that is, optimal social welfare in each period).

5.1 Optimal regulation of a localized undepletable external cost

As an example, consider a localized, undepletable externality. One of the possible defensive measures a victim can take concerns moving out of (or not moving into) the area affected. However, the regulator may be uncertain about future developments in migration patterns, or may take the stance that it is undesirable to set the incentives to the producer according to their long-run optimal values because otherwise sequential welfare losses will occur as long as the long-run situation is not realized (let alone the question of how the long run should be defined). In such cases, the regulator may wish to make the producer act in optimal response to the number of victims, thus (possibly) inducing inefficient locational behaviour on behalf of these victims. The social welfare function can in this case be represented as follows:

$$W = \mathrm{N}(Q) - A + n[M - \mathrm{C}(Q, A, D) - D] + \mathrm{L}^{\mathrm{b}}(n) - \mathrm{L}^{\mathrm{c}}(n), \qquad (20)$$

where n gives the number of victims; M, C, and D are per capita variables. The undepletable character of the external effect (that is, the 'publicness of its consumption') is reflected by the fact that the total net external costs are nC. The victims are assumed to be identical, except for their valuation of living in the affected area. The $L^{\mathrm{b}} = \mathrm{L}^{\mathrm{b}}(n)$ gives the total location benefits enjoyed by the n residents because they live in the area ($L^{\mathrm{b}}_n > 0$; $L^{\mathrm{b}}_{nn} < 0$). The $L^{\mathrm{c}} = \mathrm{L}^{\mathrm{c}}(n)$ gives the total (private) cost of location ($L^c_n > 0$; $L^c_{nn} > 0$ can be postulated in order to indicate rising marginal cost of location). The 'ordinary' defensive activities as considered in the previous section are reflected in D; the 'problematic' form of defensive behaviour here is locational behaviour.

I define the short run as the period in which the number of victims n is constant. Hence, the short-run first-order conditions of equation (20) are very much like equations (9a) to (9c):

$$W_Q = 0 \Rightarrow nC_Q = N_Q , \tag{21a}$$

$$W_A = 0 \Rightarrow nC_A = -1 , \tag{21b}$$

$$W_D = 0 \Rightarrow C_D = -1 . \tag{21c}$$

The policy implications are the same as those derived in section 4, be it that the optimal Pigouvian taxes and subsidies (or physical measures) concerning Q and A now depend on the number of victims affected. Therefore, Q and A, and via these two also D, depend on the number of victims when the government regulates so as to optimize social welfare in each period. Suppose n increases. From equations (2a) and (4), it follows that the optimal Q in equation (21a) decreases. From equation (2c), the optimal A in equation (21b) increases. From equations (2b), (2d), and (2f), the optimal D in equation (21c) therefore decreases, along with the decrease in the per-capita optimal C. By making the regulation on Q and A dependent on n, we can rewrite equation (20) as[10]:

$$W^n = \mathrm{N}(Q^n)-A^n+n[M-\mathrm{C}(Q^n, A^n, \mathrm{D}(Q^n, A^n))-\mathrm{D}(Q^n, A^n)]+(L^b)^n+(L^c)^n. \tag{22}$$

Additional regulation of the (potential) victims is now necessary in order to reach overall optimality in terms of locational behaviour. This can be seen by comparing the actual incentives faced by the $n+1$th (potential) victim considering moving into (or out of) the area with the total welfare effects of this move (that is, the optimal incentive). The individual incentive partly depends on the question of whether compensation takes place; we therefore distinguish I^C (the incentive when the victim receives no compensation and suffers the gross external cost) and I^{com} (the incentive when the victim is compensated for the gross external effect):

$$\begin{aligned} I^C = {} & M-\mathrm{C}(Q^{n+1}, A^{n+1}, \mathrm{D}(Q^{n+1}, A^{n+1}))-\mathrm{D}(Q^{n+1}, A^{n+1})+[(L^b)^{n+1}-(L^b)^n] \\ & -[(L^c)^{n+1}-(L^c)^n]- W^0 , \end{aligned} \tag{23a}$$

and

$$I^{\mathrm{com}} = M+[(L^b)^{n+1}-(L^b)^n]-[(L^c)^{n+1}-(L^c)^n]- W^0 , \tag{23b}$$

where W^0 gives the money-metric utility achievable in the best of the other possible locations, depending on the values of M, L^b, and L^c on that location. Note that I^C and I^{com} are defined such that positive values indicate attraction to the affected area. The optimal incentive, taking account of all welfare effects due to the move of an additional victim into the area, amounts to:

$$\begin{aligned} I^* = {} & [\mathrm{N}(Q^{n+1})-\mathrm{N}(Q^n)]-(A^{n+1}-A^n)+\{(n+1)[M-\mathrm{C}(Q^{n+1}, A^{n+1}, \mathrm{D}(Q^{n+1}, A^{n+1})) \\ & -\mathrm{D}(Q^{n+1}, A^{n+1})]-n[M-\mathrm{C}(Q^n, A^n, \mathrm{D}(Q^n, A^n))-\mathrm{D}(Q^n, A^n)]\} \\ & +[(L^b)^{n+1}-(L^b)^n]-[(L^c)^{n+1}-L^c)^n]- W^0 . \end{aligned} \tag{23c}$$

[10] The superscripts in equations (21)-(24) merely indicate dependence on n, rather than 'raised to the nth power'.

Therefore, I^C and I^{com} miss out on the following factors:

$$I^* - I^C = [\mathrm{N}(Q^{n+1}) - \mathrm{N}(Q^n)] - (A^{n+1} - A^n) \\ + n\{[M - \mathrm{C}(Q^{n+1}, A^{n+1}, \mathrm{D}(Q^{n+1}, A^{n+1})) - \mathrm{D}(Q^{n+1}, A^{n+1})] \\ - [M - \mathrm{C}(Q^n, A^n, \mathrm{D}(Q^n, A^n)) - \mathrm{D}(Q^n, A^n)]\}, \tag{24a}$$

and

$$I^* - I^{\text{com}} = I^* - I^C - \mathrm{C}(Q^{n+1}, A^{n+1}, \mathrm{D}(Q^{n+1}, A^{n+1})) - \mathrm{D}(Q^{n+1}, A^{n+1}). \tag{24b}$$

The expression in (24a) gives the optimal attraction to the area minus the actual attraction in absence of compensations. The first two terms give the change in the producer's welfare due to changes in production and abatement activities. The overall sign of these two terms is negative because Q^* decreases and A^* increases when n increases. The last (large) term describes the change in the other n victims' welfare due to changes in the gross external effect; the overall sign here is positive as both C and D^* decrease when n increases. The overall value of equation (24a), however, must be negative because it simply gives the change in common welfare of the producer and the n initial victims as a result of the entrance of the $n+1$th victim. As their common welfare was initially optimized, it can only have decreased. Clearly, equation (24b) is also negative, and smaller than equation (24a). Therefore, the actual attractions I^C and I^{com} are excessively large.

Figure 2 provides an illustration. A potential victim (V) considers moving to the affected area (X); thus joining a first victim that already lives there. Defensive and abatement measures are ignored, and we rely on consumer surplus arguments. Prior to the contingent location of V, the socially optimal production level is given by Q^*. However, after V has decided to locate at X, the marginal external cost function becomes twice as steep: MEC2 rather than MEC1, because of the publicness of the external cost [as a consequence, areas between MEC1 and MEC2 are of equivalent size to those between the horizontal axis and MEC1 (C = C′, and so on)]. The optimal production level decreases from Q^* to Q^{**}, and the optimal tax increases from t^* *to* t^{**}. With optimal adjustment of the production level, the decision of V to

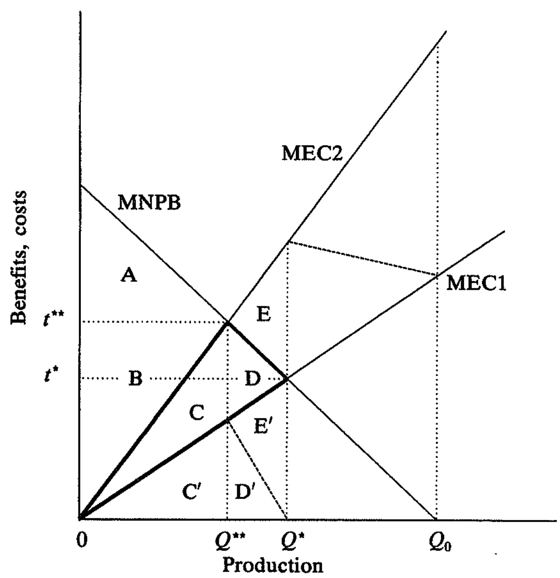

Figure 2. The welfare effects of an additional victim of a localized undepletable external cost.

locate at X poses a welfare loss on the rest of the society equal to area D. This is the algebraic sum of the decrease in the producer's benefit of D′+E′+D = 2D+E, and the increase in the first victim's welfare of (D′+E′). Therefore, V's choice for locating at X is only efficient if it yields V extra welfare (compared with the second-best choice) of at least the optimal external cost he or she suffers from living there, plus the welfare loss he or she poses on the rest of the society (C+D). Consequently, the bold triangle represents the total (negative) incentive that V should receive for locating in the affected area in order to secure efficient location behaviour. This is equal to the decrease in optimal net social welfare after V has located at X.[11] The victim should, therefore, not be compensated for C, and should be levied a *location tax* equal to area D.

The absolute values of equations (24a) and (24b) give the general expressions for the optimal location taxes to be levied both on potential and on actual victims in order to sequentially optimize the number of victims when the regulator follows the policy of sequential welfare optimization. Also from equations (24a) and (24b) it follows that compensation is not in order here: the location tax implied by equation (24b) exceeds the one implied by (24a) exactly by the value of full compensation. Moreover, lump-sum compensations as described in section 4 (that is, lump-sum compensation of the gross external cost irrespective of the level of 'ordinary' defensive activities undertaken) are also ruled out. That is not surprising: 'true' lump-sum compensation in this setting would mean compensations independent of actual locational decisions. This underlines the small practical relevance of lump-sum compensations: in the case of a localized externality, lump-sum compensations involve payments to all potential victims (everyone who might ever decide to move to the affected area). Such lump-sum compensations of course bare only very limited relation with the actual welfare effects due to the externality, and therefore make little sense from an equity point of view.

The optimal number of victims is illustrated in figure 3. The horizontal axis gives the number of victims. MLB gives the *marginal location benefits*, defined here as $M+(L^b)^n-W^0$. MOEC gives the *marginal optimal (gross) external cost* for additional victims as implied by equations (21) and (22). MSCL gives the *marginal social cost of location* including the welfare effects on the producer and the existing victims; it follows from adding the absolute value of equation (24a) to MOEC.

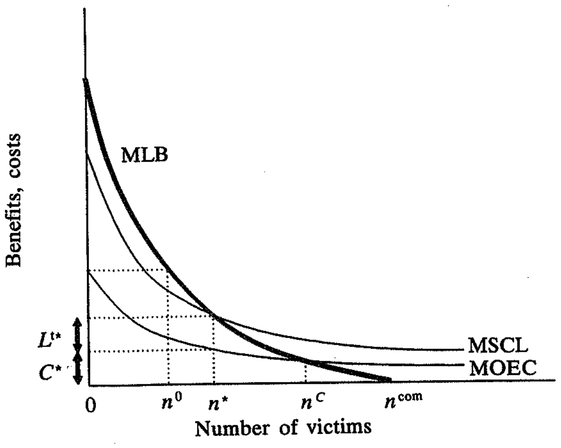

Figure 3. The optimal number of victims of a localized undepletable external cost.

(11) The optimal net social welfare is A+B+C+D before, and A+B after V locates at X.

The general shape of MOEC and MSCL follow from the notion that with an increasing number of victims, the marginal welfare effects of an additional victim will decrease. However, they will not become zero as long as the activity remains in existence. For convenience, we assume zero land prices.

If the victims are compensated for the external cost (or if the external cost would not exist) n^{com} victims choose the area as their location. However, without compensations, a certain number of potential victims will find that the external cost exceeds their marginal location benefit. Then, n^c victims result. The socially optimal number of victims is given by n^*. Here, the marginal social cost of location is equal to the marginal location benefit.(12) This optimum can be reached by levying the optimal location tax L^{t*} and refraining from compensation of the optimal external cost C^*. In the absence of any regulation, n^0 victims result. The victims face the nonintervention level of the gross external cost (the optimal gross external cost for $n = 0$).(13) Figure 3 in fact describes situations where no land prices exist; in particular, when the external effect affects a public area.(14) The allowance for flexible land prices does not really change the results. All n's in figure 3 coincide only when the supply curve $\mathrm{L}^c(n)$ is perfectly inelastic.(15) In that case, an infinitely flexible land price would completely off-set the effect of the external cost on the (optimal and actual) number of victims. Likewise, a location tax would immediately be absorbed by an equivalent drop in the rent, thus leaving the number of victims unaffected. Generally, the more elastic the supply of dwellings, the more relevant the issues discussed above. As the supply of dwellings is usually more inelastic in the shorter run, it is worth underlining that location taxes are more relevant in the longer run.

Externalities thus have a reciprocal character. As soon as victims indeed value living in the affected area enough to be willing to accept the optimal incentive, this will be 'rewarded' with a decline in the optimal external effect. When a growing number of victims choose to live in the area, the optimal production, and hence the externality, may be reduced to zero, reflecting the fact that the existence of the activity at that location was apparently socially unwarranted.

5.2 Coasian negotiations on a localized undepletable external cost

Thus far, I have considered the optimal *regulation* of a localized depletable externality in a dynamic setting, which turned out to involve regulation of both its producer and its victims. The natural question rises whether Coasian negotiations would not offer a superior device in such cases. In fact, it is often asserted that Coasian

(12) MLB is zero at $n = n^{\mathrm{com}}$, whereas MSCL will never be zero, so there is a nonzero outcome n^* provided MLB(0) > MSCL(0). Otherwise, the corner solution $n^* = 0$ prevails.

(13) The fact that n^0 is quite close to n^* indicates that nonintervention may lead to a total number of victims which might be somewhere near the optimal number, as the excess level of the external cost will to a certain extent serve as a substitute for the location tax. This does not of course mean that nonintervention may coincidentally lead to Pareto efficiency. Contrary to optimal regulation of the external cost and locational behaviour, nonintervention involves important welfare losses.

(14) For instance, figure 3 may describe the optimal number of victims of external accident costs of road transport. The victims might be pedestrians, location now means walking along a road, and MLB gives the benefits of walking. From an efficiency viewpoint, pedestrians should not be compensated for the expected accident costs posed upon them, and should actually be taxed for walking.

(15) Although the aggregate supply of land is usually perfectly inelastic, the supply curve for a sector (for example, housing) is upwards sloping when the sector has to compete with other sectors for the use of land.

negotiations are particularly relevant for small-number cases, where (prohibitively) high transaction costs are less likely to undermine their theoretical attractiveness. As the concept of a *localized* externality suggests a natural limit on the number of actors involved in the negotiations, it is worthwhile to investigate the performance of this scheme under these circumstances. From section 4, we know that Coasian negotiations provide short-run efficient outcomes as long as the negotiations simultaneously concern Q, A, and D. Likewise, Coasian negotiations on a localized undepletable externality might preserve their efficient workings if, apart from negotiations on Q, A, and D, additional negotiations concerning locational behaviour (that is, concerning n) take place. This will be discussed below in terms of equations (23) and (24), and in terms of figure 2 (as indicated by terms between square brackets). I will consider three possible distributions of property rights: (1) assigned to the producer, (2) assigned to the initially existing victim(s) only, and (3) assigned to all victims, including new entrants.

First, consider the case where the producer holds the property right. For the new optimum to settle after the location of the $n+1$th victim, the producer will require an additional transfer from all victims (at least) equal to the first two terms in equation (24a), which we call ΔW^{p}[2D + E]. The n existing victims are prepared to bargain over the location of the $n+1$th victim by offering (part of) their marginal benefit from this entrance. This benefit is given by the last large term in equation (24a), which we call $\Delta W^{n\mathrm{v}}$ [D′ + E′]. Clearly, up to the optimal number of victims, additional victims are willing to bare the sum of the 'new' optimal gross external cost represented by the last two terms in equation (24b), which we call G^{n+1} [C], and the additional transfer the producer requires in excess of what the n existing victims are willing to offer, given by $-(I^{*}-I^{C})$ in (24a) [D]. Provided full negotiations take place on all relevant issues, including locational behaviour, the marginal potential victim faces exactly the optimal incentive I^{*} in equation (23c), and we may expect the overall optimal outcome to emerge. Only then are the possible mutual gains from negotiations exhausted.

There is, however, a particular problem associated with the assignment of the property right to the producer of an undepletabled externality, which is closely related to the problem of voluntary private provision of public goods (for instance, see Bergstrom et al, 1986). Suppose for instance that n identical victims suffer from the externality, the adverse affects of which they can reduce either by offering the producer Coasian compensations for reductions in the emission E of the externality, or by means of (private) defensive activities D. Without cooperation among the victims, we may assume each victim to exhibit Nash-like behaviour. That is, when deciding on a bid, b, to be made to the producer, the victim takes the sum of the other victims' bids, $B^{-\mathrm{v}}$, as given. Hence, a victim acts so as to maximize

$$W^{\mathrm{v}} = M-\mathrm{C}(D,\mathrm{E}(B^{-\mathrm{v}}+b))-D-b\,, \tag{25}$$

leading to

$$C_D = -1\,, \tag{26a}$$

$$C_E E_b = -1\,, \tag{26b}$$

where $E = \mathrm{E}(B^{-\mathrm{v}}+b)$. This behaviour is easily seen to imply underprovision of the 'public good' of reducing the emission. The optimal conditions for the victims' behaviour follows from maximization of their common welfare, being n times the representative victim's welfare W^{v}:

$$nW^{\mathrm{v}} = n[M-\mathrm{C}(D,\mathrm{E}(n\beta))-D-\beta] \tag{27}$$

where β gives the average (per victim) Coasian bid. The first-order conditions are

$$C_D = -1\,, \tag{28a}$$

and

$$C_E E_\beta = \frac{-1}{n}\,, \tag{28b}$$

where $E = \mathrm{E}(n_\beta)$.

Equations (26b) and (28b) show that, because of the 'free-rider' problem associated with the voluntary provision of public goods, Nash behaviour implies individual 'undervaluation' of reductions in the emission with a factor which is proportional to the number of victims. Therefore, with the property right assigned to the producer of an undepletable externality, we may expect a below-optimal reduction in the emission of the externality, and therefore an above-optimal level of private defensive activities. Unless the victims gather their interests in some sort of victims' union, such Coasian negotiations do not lead to overall efficiency. However, individual victims will have an incentive to quit such unions and go free riding, which makes the voluntary emergence of these unions unlikely.

In the second case, the initially existing victims possess the property right. The new short-run optimum is reached by means of some sort of two-stage bargaining between the new victim and the producer, where the existing victims act as an intermediate. In order for the optimal outcome to settle, the new victim should make a transfer to the existing victims which (at least) enables them to make a mutually profitable bid to the producer concerning the reduction in the emission of the externality (such a bid in fact takes place in terms of a reduction in the producer's payment to them in exchange for further reductions in the emission). As the existing victims have a certain interest in such reductions as well, the minimum transfer required from the new one amounts to $\Delta W^{\mathrm{p}} - \Delta W^{n\mathrm{v}}$ [D]. Furthermore, the new victim will receive no compensation for the gross external cost G^{n+1} [C]. Again, we expect entrance to take place up to the optimal number of victims. Note, however, that with more than one additional victim entered, we may again expect the free-rider problem, as discussed above, to emerge.

In the third case, the new victim receives a property right after having located in the affected area. Therefore, the free-rider problem will not occur. The minimum transfer a victim will then demand from the producer amounts to the optimal gross external cost G^{n+1} [C]. Potential victims initially face a below optimal (that is, a zero) incentive for staying out of the affected area. Only if additional bargaining on locational decisions takes place will the optimal number of victims be reached. In the first place, the producer is prepared to offer payments up to the minimum transfer just mentioned (that is, G^{n+1} [C]) in order to keep the new victim out. In addition, the producer is prepared to offer a payment up to the value of ΔW^{p} [2D + E]. The existing victims, however, are prepared to pay the new one up to $\Delta W^{n\mathrm{v}}$ [D + E] if he or she enters the area. At the margin therefore the potential victim faces exactly the optimal incentive for entering the affected area, be it that in this case he or she foregoes a payment $G^{n+1} + \Delta W^{\mathrm{p}} - \Delta W^{n\mathrm{v}}$ [C + D] if he or she actually does enter. Clearly, this type of bargaining creates perverse incentives for 'potential' victims. Simply by threatening to enter the area, they are able to receive the payment just mentioned. If the producer (and the existing victims) decide not to make any such transfers in order to prevent this behaviour, potential victims clearly face a below-optimal incentive for staying out of the affected area. Note that, under the second scheme, the existing victims do not have the same possibility for strategic behaviour. The incentive of the existing $n+1$th victim to move out is the payment $G^{n+1}+\Delta W^{\mathrm{p}}-\Delta W^{n\mathrm{v}}$ [C+D] he or she foregoes by not doing so. Obviously, the victim is only able to collect his money from the producer and the n other existing victims if he or she really does move out.[16]

In section 4, direct compensations were found not to lead to inefficient behaviour of the victims in terms of undertaking below-optimal defensive measures, provided negotiations on the level of defensive activities would take place. It is noteworthy that with localized undepletable externalities, direct compensation to new victims induce them to exhibit the strategic behaviour just discussed. That is, they are able to receive a payment $G^{n+1}+\Delta W^{\mathrm{p}}-\Delta W^{n\mathrm{v}}$ when threatening to enter the area. Hence, the negotiations which may follow from direct compensations in this case, although preserving the optimal marginal incentive, may actually provoke adverse strategic behaviour of potential victims.

We may conclude that, provided additional negotiations on locational decisions do take place, Coasian negotiations are *in principle* capable of providing efficient outcomes in case of a localized undepletable externality. However, although Coasian negotiations are often thought to be especially attractive in small number cases (that is, in case of localized externalities), because of the relatively low transaction costs in such situations, the envisaged efficient outcomes may be seriously endangered by induced strategic or free-rider behaviour.

5.3 A short remark on entry-exit decisions of producers

The consequences of entry-exit behaviour of producers have played an important role in the issue of Pigouvian subsidization versus taxation (for example, see Pearce and Turner, 1990, pages 107-109). Although the short-run responses to both kinds of measures will be the same, a subsidy will in the long run attract additional firms to the industry, whereas a tax will drive a number of firms out of the industry. This implies that Pigouvian subsidization will eventually result in higher production and pollution levels at the industry level than does Pigouvian taxation. Cropper and Oates (1992, page 682) observe in this respect that only "if firms bear the total cost of their emissions will the prospective profitability of the enterprise reflect the true social net benefit of entry and exit into the industry". For the model considered in section 3, only those schemes that charge the producer according to the full compensation criterion yield long-run efficient entry-exit behaviour of producers. These schemes are: (a) direct compensation, (b) Coasian negotiations with the property right assigned to victims (provided the producer is the strongest bargainer), and (c) Pigouvian taxation in the case of constant marginal external cost. Other schemes leading to the short-term optimization of an external cost require additional (lump-sum) taxes or subsidies. In section 4, the optimal charge for accomplishing long-run efficient producer entry-exit behaviour simply amounts to the gross external cost (provided that both production and abatement are optimal). As far as Coasian negotiations are concerned, the property right should clearly be assigned to the victims. In a competitive market equilibrium, the entrance of new producers will take place until excess profits have disappeared. As a consequence, the maximum transfer victims are able to receive in such negotiations is then exactly

(16) For the payments $G^{n+1}+\Delta W^{\mathrm{p}}-\Delta W^{n\mathrm{v}}$ to materialize, we have to assume some sort of trilateral bargaining over locational discussions. For instance, although the producer is prepared to pay $G^{n+1}+\Delta W^{\mathrm{p}}$ to keep victims away, the actual offer in direct negotiations with them is $G^{n+1}+\Delta W^{\mathrm{p}}-\Delta W^{n\mathrm{v}}$ provided the other n victims let the producer know that they are willing to accept (demand) reductions (increases) in transfers received up to $\Delta W^{n\mathrm{v}}$ when entrance (exiting) does take place.

equal to the full compensation of the gross external cost. Finally, in case of localized external costs, such as discussed in section 5.1, the producers' entry-exit behaviour is optimized when they face the optimal gross external cost *on a certain location*. Whenever external costs differ between locations, for instance because of differences in the optimal numbers of victims, the producer will then receive the correct incentives for any locational decisions. Therefore, we may conclude in general that the long-run efficiency condition for producers coincides with the equity condition of full compensation.

6 Conclusion

Externalities comprise both efficiency aspects and equity aspects. The potential Pareto improvement criterion usually applied in analysis of the economics of externalities is solely concerned with efficiency because it bypasses the question of interpersonal utility comparison. However, in the practice of policymaking, equity issues are often at least as important. I have investigated the puzzling relations between equity and efficiency issues in the economics of externalities. The main conclusions are as follows.

First, external costs, being the monetary value of some external effect, are defined in terms of the victims' willingness to pay for reductions in this effect. As the individual willingness to pay for such reductions was seen to be inversely related to the marginal utility of money, an implication is that equal exposures to a physical effect mean, ceteris paribus, larger external costs for higher income groups than for lower income groups. Intuitive objections against this implication reflect either dissatisfaction with the existing income distribution, or the assignment of some demerit character of the effect for lower income groups. At any rate, straightforward application of the concept of external costs may ignore important equity aspects *within* the population of victims. However, in this paper I have focused on equity aspects between the supplier(s) and the receptor(s) of the effect only.

In the most simple static model, efficiency can be achieved by means of (optimal) regulation, internalization, or direct compensation, although each of them has different distributional consequences. However, compensation and optimization are in principle perfectly compatible in such settings. When allowing for the possibility of defensive activities on behalf of the victim of an external cost, direct compensations may remove the optimal incentive to engage in the efficient level of defensive activities. This, however, will not occur when the gross external cost rather than the net external cost is to be compensated, and negotiations between the producer and the victim on the level of defensive activities take place. Therefore, in a static setting, direct compensations are not necessarily incompatible with efficiency. Since direct compensation can be seen as a restricted form of assigning property rights to the victim, this is not too surprising; Coasian negotiations were seen to lead to efficiency in this setting. With the property right assigned to the victim, Coasian negotiations will, in addition, at least lead to full compensation of the gross external cost. Furthermore, (Pigouvian) tax revenues resulting from a producer's regulation may be transferred in a lump-sum fashion to the victims without endangering the optimal outcome. However, the incentives to perform defensive measures are by definition only optimal if the effect is not considered to have a demerit character.

In a dynamic context, a regulator faces a particular difficulty when following a policy of sequential welfare optimization, which may be done because of uncertainty, or in order to avoid sequential short-run welfare losses. When direct regulation of the producer of the externality is adjusted in optimal response to the victims' behaviour, below-optimal incentives for defensive behaviour result. Therefore, it creates a need for regulation of victims, either in terms of subsidization of defensive activities or in terms of taxation of a lack of defensive activities. The second is particularly relevant in case of a localized externality, where a location tax was seen to be necessary in order to sequentially realize the optimal number of victims. Any form of compensation was seen to act against efficient location behaviour in this setting.

The performance of Coasian negotiations in such a localized-dynamic context was seen to be quite problematic. First, Coasian negotiations in this setting lead to optimization of the effect only if additional negotiations on locational decisions take place. However, although Coasian negotiations are often thought to be especially attractive in small-number cases (such as localized externalities), the envisaged efficient outcomes may be seriously endangered by induced strategic or free-rider behaviour. Assigning property rights to the producer may result in free riding of the victims in the process of Coasian negotiations, ruling out efficient outcomes. Comparable free riding among 'new' victims may emerge when only the initially existing victims receive a property right. On the other hand, assigning property rights to all victims, including new ones, may provoke adverse strategic behaviour on behalf of 'potential' victims, because in this case the optimal locational incentive received is in terms of foregoing a payment. Second, the assignment of the property rights is not a matter as innocent as it is in static settings. In order to secure long-run entry-exit behaviour of producers, they should face incentives exactly equal to the equity criterion of full compensation. In a competitive market equilibrium the entrance of new producers will take place until excess profits have disappeared and victims are not able to receive any Coasian transfers exceeding the gross external cost, so the assignment of property rights to the victims is preferable from both an equity and a dynamic efficiency point of view. All in all, in a dynamic context, Coasian negotiations are certainly not as attractive as they may seem from a static perspective.

We may conclude that, in a static context, the compensation and optimization of external costs are more likely to be compatible as long as the victim(s) of the externality are actively engaged in direct negotiations over this compensation. In a localized-dynamic context, however, compensation is incompatible with optimization. Moreover, victims of an external cost should then even be charged for being a victim.

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